Conservation Biology

Special Section: **Moving from Citizen to Civic Science to Address Wicked Conservation Problems**

Contributions of paraecologists and parataxonomists to research, conservation, and social development

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Abstract: *Citizen science has been gaining momentum in the United States and Europe, where citizens are literate and often interested in science. However, in developing countries, which have a dire need for environmental data, such programs are slow to emerge, despite the large and untapped human resources in close proximity to areas of high biodiversity and poorly known floras and faunas. Thus, we propose that the parataxonomist and paraecologist approach, which originates from citizen-based science, is well suited to rural areas in developing countries. Being a paraecologist or a parataxonomist is a vocation and entails full-time employment underpinned by extensive training, whereas citizen science involves the temporary engagement of volunteers. Both approaches have their merits depending on the context and objectives of the research. We examined 4 ongoing paraecologist or parataxonomist programs in Costa Rica, India, Papua New Guinea, and southern Africa and compared their origins, long-term objectives, implementation strategies, activities, key challenges, achievements, and implications for resident communities. The programs supported ongoing research on biodiversity assessment, monitoring, and management, and participants engaged in non-academic capacity development in these fields. The programs in Southern Africa related to specific projects, whereas the programs in Costa Rica, India, and Papua New Guinea were designed for the long term, provided sufficient funding was available. The main focus of the paraecologists' and parataxonomists' activities ranged from collection and processing of specimens (Costa Rica and Papua New Guinea) or of socioeconomic and natural science data (India and Southern Africa) to communication between scientists and residents (India and Southern Africa). As members of both the local land user and research communities, paraecologists and parataxonomists can greatly improve the flow of biodiversity information to all users, from local stakeholders to international academia.*

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Contribuciones de los Paraecólogos y los Parataxónomos a la Investigación, la Conservación y al Desarrollo Social

Resumen: *La ciencia ciudadana ha estado ganando ímpetu en Estados Unidos y en Europa, en donde los ciudadanos son alfabetizados y con un continuo interés por la ciencia. Sin embargo, en los países en desarrollo – que tienen una urgente necesidad de información ambiental – dichos programas emergen lentamente, a pesar de los grandes recursos humanos sin utilizar en las proximidades de las áreas de biodiversidad alta y con flora y fauna poco conocidas. Por esto, proponemos que la estrategia de los parataxónomos y los paraecólogos, que cual surge a partir de la ciencia basada en la ciudadanía, es muy adecuada para las áreas rurales de los países en desarrollo. Ser un parataxónomo o un paraecólogo es una vocación que conlleva una ocupación de tiempo completo apoyada por un entrenamiento extensivo, mientras que la ciencia ciudadana involucra la participación de voluntarios. Ambas estrategias tienen sus méritos dependiendo del contexto y de los objetivos de la investigación. Examinamos cuatro programas actuales de paraecológos y parataxónomos en Costa Rica, India, Papúa Nueva Guinea y en el sur de África, y comparamos sus orígenes, objetivos a largo plazo, estrategias de implementación, actividades, retos clave, logros e implicaciones para las comunidades residentes. Los programas apoyaron a la investigación continua sobre la evaluación, el monitoreo y el manejo de la biodiversidad y los participantes se involucraron en el desarrollo de capacidades no-académicas dentro de estos campos. Los programas en el sur de África se relacionaron con proyectos específicos, mientras que los programas en Costa Rica, India y Papúa Nueva Guinea fueron diseñados para el largo plazo, siempre y cuando se tuviera suficiente financiamiento disponible. El enfoque principal de las actividades de los paraecólogos y los parataxónomos varió desde la recolección y el procesamiento de especímenes (Costa Rica y Papúa Nueva Guinea) o de datos socioeconómicos y de ciencias naturales (India y sur de África) hasta la comunicación entre los científicos y los residentes (India y sur de África). Como miembros de la comunidad de usuarios locales del suelo y de la comunidad científica, los paraecólogos y los parataxónomos pueden mejorar enormemente el flujo de información sobre la biodiversidad para todos los usuarios, desde accionistas locales hasta académicos internacionales.*

Palabras Clave: conservación de suelo virgen, cooperación para el desarrollo, desarrollo de capacidad no-académica, evaluación de la biodiversidad, investigación participativa, manejo de recursos naturales

Introduction

Citizen science—a scientific exercise in which members of the public are involved as volunteers in data capture, sharing, and sometimes analysis—has a long history (Silvertown 2009; Miller-Rushing et al. 2012). Some of the oldest and well-known citizen science projects include the Christmas Bird Count (U.S.A.), which has been going on for over a century (The Audubon Society 2015), and the U.K.'s Big Garden Birdwatch, which has been running for nearly 40 years (Birdwatch 2015). Citizen science is common in countries where engaging with nature is relatively commonplace among the general public and where there are numerous scientists and organizations willing to organize them (Chandler et al. 2012). The massive potential of citizen science in ecological research and engagement has found global appeal (Chandler et al. 2012), but volunteers are not widely available in many areas, and this inhibits the uptake of citizen science projects. This is especially true for rural areas of biodiverse and resource-poor countries, where there is a dire need for high-quality environmental data. The lack of such data is an obstacle for the planning and implementation of sustainable environmental management, especially in wildlands.

We consider the paraecologist and parataxonomist approach a bridging strategy that leads to professionalism among non-academic members of the research team, through permanent employment and capacity development. On the basis of the definition suggested by Janzen (1992, 1993), a paraecologist or parataxonomist is a resident professional with local knowledge who lacks formal academic training, being largely trained on-the-job, in one or more fields of ecological and taxonomic science. He or she contributes to scientific research and local capacity development and enhances communication between local and scientific communities. We perceive the paraecologist and parataxonomist concepts to be very similar, but each emphasizes a different major product. In contrast to citizen scientists, paraecologists and parataxonomists are employed and are full members of a research team. Paraecologists or parataxonomists on the one hand, and citizen scientists on the other, have often been mentioned in the same breath in connection with biodiversity data sampling (e.g., Abadie et al. 2008; Cardoso et al. 2011; Casanovas et al. 2014). We reviewed 4 currently running paraecologist or parataxonomist approaches and compared these with the citizen science approach.

Several publications describe and evaluate single paraecologist and parataxonomist programs (see Paraecologist 2015), many of which we reference. We reviewed 4 programs currently running in Costa Rica, India, Papua New Guinea, and southern Africa and compared their practices with common practices in citizen science. We determined program origins, objectives, implementation, activities, benefits, key achievements, challenges, differences between paraecologists and parataxonomists and citizen scientists, and implications of participation for paraecologists or parataxonomists and neighboring communities.

Program Identification and Review

Two international workshops about paraecologist and parataxonomist programs worldwide were held (2011 and 2014). Participants selected 4 ongoing programs that varied in their research focus on taxonomy, applied ecology, and conservation and for which sufficient first-hand or secondary information was available (Table 1). In the second workshop, the research questions for this article were identified and information sources were reviewed (peer-reviewed publications, grey literature, websites, and videos).

Programs

Parataxonomist Program in Costa Rica

The Costa Rican parataxonomist program in Area de Conservacion Guanacaste (ACG) was initiated in 1989 (Janzen et al. 1993; Basset et al. 2004) by a partnership formed between the non-governmental, non-profit organization INBio (the National Biodiversity Institute of Costa Rica) and the administrative authorities of ACG (ACG 2015) (hereafter INBio-ACG) (Table 1). The program implements INBio's goal of conducting an ambitious national species inventory of Costa Rica's wildland biodiversity to ensure its conservation through non-damaging uses by society (e.g., Lewin 1988; Gamez 1991; Janzen 2004). An important, albeit not the principal, use of biodiversity information was bioprospecting, undertaken by a specific team within INBio. Bioprospecting was developed in parallel with the work of conducting the national inventory. Between them, a broad offering of educational projects is aimed at all sectors of society to help promote rapid, self-reinforcing taxonomic literacy and an improved awareness of biodiversity's relevance (e.g., Janzen 1991, 1998, 2004). This project was the first initiative to involve formally identified and trained parataxonomists in scientific biodiversity inventories (Janzen 1991; Gamez 1999).

The first parataxonomists initially took 6-month training courses (Janzen 1991; Hambleton 1994; Simons 2011) and had opportunistic apprenticeships provided through their close work with INBio curators and international academic taxonomists (Janzen 1991, 2004). Parataxonomists work full time throughout Costa Rica, with special emphasis on ACG (Janzen 1991). Their main tasks are to collect plant, mollusc, fungus, and insect species. Butterflies, moths, and caterpillars, and their parasitoids are targeted in particular in ACG (Janzen et al. 2009; ACG 2015; GDFCF 2015) and collected with their potential host plants, upon which they are reared in special rearing barns (Janzen 2004). Parataxonomists also process collected specimens (taxonomic identification, data entry, photographing, maintaining web data, etc.) and assist with teaching in training courses for newcomers (Janzen 1991, 2004). Since 2003 the parataxonomists have also been involved in the collection and processing of specimens for DNA barcoding (Janzen & Hallwachs 2011) and placing species pages on the ACG web site (http://www.acguanacaste.ac.cr/paginas-de-especies).

New Guinea Binatang Research Center in Papua New Guinea

The paraecologist initiative (Table 1) in Madang (Papua New Guinea [PNG]) started in 1994 as a small team of permanently employed paraecologists assisting in studies of plant–herbivore interactions in rainforest ecosystems. The program has expanded to include ecological research on plants, insects, and vertebrates. Several large research projects have been completed under this program, including the study of plant–herbivore food webs in tropical forests (Novotny et al. 2010), monitoring of >250,000 individual plants in a 50-ha forest plot (Anderson-Teixeira et al. 2015), and studies of invertebrate and vertebrate biodiversity and ecosystem change along an elevational gradient (Sam et al. 2014). The paraecologist team also includes students from PNG and overseas, works with indigenous landowners on rainforest conservation (Novotny 2010), and participates in the country's biodiversity and environmental quality surveys for the government and local industry. The team is established as a non-profit organization (New Guinea Binatang Research Center [BRC]) registered in PNG and works in collaboration with national and overseas academic institutions.

Paraecologists are recruited locally, from the most promising field assistants hired from communities at the study sites, and nationally through advertising for available positions. This strategy of local recruiting of paraecologists engenders conservation and science-friendly attitudes in forest-dwelling communities, as well as their direct involvement in the research. This combination of hiring strategies has resulted in a diverse group of paraecologists, from people with grade 6 to 8 educations, to rural farmers, to new university graduates in biology. Paraecologists are trained on the job by resident and visiting scientists and doctoral candidates, as well as more senior paraecologist staff. Paraecologists alsot participate in the International Course of Tropical Ecology with

Table 1. Overview of the paraecologist and parataxonomist programs examined.

Name	*National Biodiversity Institute of Costa Rica-Area de Conservacion Guanacaste*	*Binatang Research Center in Papua New Guinea*	*BIOTA Southern Africa and The Future Okavango*	*Caracal Research and Conservation Project*
Abbreviation	INBio-ACG	BRC	BIOTA and TFO, respectively	CRCP
Duration	since 1978 (Janzen 2004), first formal training courses 1989, 1990, 1992 (Janzen 1991), 1993 (Janzen et al. 1993)	since 1994 (Basset et al. 2000)	BIOTA: 2004–2010 (Schmiedel et al. 2010); TFO: 2011–2015 (Schmidt et al. 2013)	since 2011
Name used	Parataxonomist	Paraecologist	Paraecologist	Paraecologist
Hosting organization or institution	Area de Conservacion Guanacaste, Instituto Nacional de Biodiversidad, Guanacaste Dry Forest Conservation Fund	The New Guinea Binatang Research Center, Madang, Papua New Guinea	Research projects BIOTA Southern Africa and The Future Okavango	Madhya Pradesh Caracal Conservation and Research Project
Initiator	Daniel H. Janzen, Winnie Hallwachs	Larry Orsak, Yves Basset, Vojtech Novotny	Ute Schmiedel	Shekhar S. Kolipaka
Main funder	international agencies and foundations, Costa Rican government, private donors (Janzen et al. 1993); currently Parataxonomists Program from Area de Conservacion Guanacaste funded by direct input from ACG and the Guanacaste Dry Forest Conservation Fund (GDFCF), which raises funds from a variety of private sources	U.S. National Science Foundation, Grant Agency of the Czech Republic, Czech Academy of Science, U.K. Darwin Initiative, U.S. Christensen Fund, Swire and Sons (funds mostly research, partly capacity building and conservation grants)	German Federal Ministry of Education and Research (BMBF)	Madhya Pradesh State Biodiversity Board and Leiden University Study Grant to Shekhar Kolipaka
Countries	Costa Rica	Papua New Guinea	BIOTA: South Africa, Namibia; TFO: Angola, Botswana, Namibia	India
Employer	Costa Rican Government, ACG, GDFCF, INBio	The New Guinea Binatang Research Center	BIOTA: Namibian and South African National BIOTA Steering Committees; TFO: local organizations and institutions (Kalahari Conservation Society, Namibia Nature Foundation, Instituto Superior de Ciências de Educação)	Madhya Pradesh Caracal Conservation and Research Project
Disciplinary background of project	biodiversity inventory, taxonomy, plant–animal interactions, tropical ecology, conservation through biodiversity development, academic and applied research, education, restoration biology, biocultural restoration, administration	biodiversity assessment, taxonomy, rainforest ecology, plant–animal interactions (plants, insects, vertebrates)	biodiversity monitoring and natural resource management	biodiversity assessment, social surveys, monitoring human–wildlife interaction, dissipation of project findings to local communities

continued

Table 1. *continued*.

Name	*National Biodiversity Institute of Costa Rica-Area de Conservacion Guanacaste*	*Binatang Research Center in Papua New Guinea*	*BIOTA Southern Africa and The Future Okavango*	*Caracal Research and Conservation Project*
Main tasks	full-time collecting (and rearing) and processing of specimens and natural history information for the inventory site in which person is resident and specialized (Janzen 2004; Janzen et al. 2009; Janzen & Hallwachs 2011)	organizing field expeditions, sampling data and specimens in the field, conducting field experiments, processing specimens for museum collections and DNA analysis, morphotyping and identifying species, computer data entry	biodiversity and environmental monitoring, socio-economic research, acting as local resource person, information sharing with stakeholders, working with student researchers on their research	wildlife surveys, social surveys, collecting information on livestock herding and fencing strategies, building working relationships with local community groups to address wildlife–human conflict issues
Additional tasks	assisting with teaching functions in initial 6-month courses for newcomers (Janzen 1991, 2004) and subsequent apprenticeships for later generations of parataxonomists; teaching field biology to all neighboring schools (Janzen 1991)	environmental awareness raising in schools, working with postgraduate students on their research, assistance to communities with conservation projects	environmental awareness raising at local schools	learning new skills: taking photos, documenting, working with computers, learning to drive, etc. (Kolipaka et al. 2015)
Selection process	application from the adjacent communities and highly competitive interviews (Janzen 2004)	recruited from best field assistants hired at the study sites or hired through nation-wide search for best applicants based on resumes and interviews	partly community driven (shortlist provided by community leaders) and partly through applications, interviews and personal contacts	senior paraecologists shortlist potential new recruits, shortlisted recruits are interviewed, selected candidates are involved in the project for one month and based on performance their positions are finalized
Selection criteria	self-motivation, long-term dedication, on-the-job growth, and curiosity, maturity irrespective of age, no longer in formal education system, able to read and write, eager, over 16 years old	curiosity about nature, interest in research, capacity to learn, compatibility for team work, initiative	interest in their social and natural environment, preparedness to work outdoors	willingness and ability to work with little supervision, to travel and work outdoors and also from home if work demands, to work on nature-related topics and also with local communities
Minimum level of formal education	none other than being able to read and write, most with 4–6th grade educations	6th grade, but most with 8th grade to completed B.S. degree	none (grade 10–12)	some reading and writing skills, no need for formal education
Background of the candidates	park guards, farmers, ranchers, housewives, babysitters, store clerks, taxi drivers, former high school students, forest rangers, game wardens, gov. administrators, etc. (Janzen 1991)	farmers, high school, university students	rural, school leavers, previous working experiences in mining, education, NGOs, voluntary community work	rural, almost always from the local area, good knowledge of local fauna, flora, or good understanding of local communities and their cultures

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Table 1. *continued.*

Name	*National Biodiversity Institute of Costa Rica-Area de Conservacion Guanacaste*	*Binatang Research Center in Papua New Guinea*	*BIOTA Southern Africa and The Future Okavango*	*Caracal Research and Conservation Project*
Number of PEs or PTs employed simultaneously	34 in the field and 5 in urban San Jose (INBio)	25	BIOTA: 8–10; TFO: 3	3–4
Working times	full time, flexible hours; 20 days a month, distributed according to need	full time, flexible hours	full time, flexible hours	3 full time; 1 is involved when there is sufficient work
Training	5–6 months of full-time formal (site-specific) field-taught learning, apprenticeship to other parataxonomists or scientists, continuous on-the-job training (feedback from taxonomist community) (Janzen 2004)	trained on the job by resident scientists, PhD candidates, and senior paraecologists, intense during 6 months probation, continues for additional 2.5 years before reaching senior status	2–3 weeks of training courses annually, participation and oral presentations, on-the-job training while working with scientists and via Internet	1 month at the start of employment, on-the-job training once every 3 months for a 4–5 days, close mentoring via skype and phone
Additional training options	how to build a database and manage it and upload it to the web, drive and care for a car, how to use a computer and a topographic map, how to use a field guide in a foreign language, what is administration and why, structure and content of environmental legislation and conservation propaganda, funding for research, personal relationships with government and NGO administrators, how to feel self-confident in the face of depreciatory assault, how to teach, etc. (Janzen et al. 1993)	international course in tropical ecology (in PNG, for paraecologists and students), overseas training experience (one training trip per staff member)	driving license, use of GIS, use of computer and Internet, producing and interpreting graphs, reading topographic maps, participatory video, participation in regional conferences, preparing and delivering talks, reporting, budget administration, conflict resolution, additional certified training courses to improve job chances for the time after the project	use of computers, documenting and taking notes, using data collection devices, driving of motorcycle and jeep
Supervision	work self-reliantly with feedback from taxonomist community, minimal supervision, occasional feedback at the INBio facility over 3 days every 2–3 months, when all parataxonomists gather at the INBio and their recently collected material is gone over by curators and visiting scientists (Janzen et al. 1993); today this process occurs in the field in ACG, not at INBio	resident scientists and PhD students, paraecologist team leaders, constant feedback from overseas collaborators by email	personal mentors at the site or overseas via monthly reports, email, and telephone	mentoring via telephone; collected data transferred to program coordinator on a day-to-day basis and feedback is provided to the paraecologists daily paraecologist briefing and reporting for at least 10 min every day over phone when supervisor is not at the site

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Table 1. *continued*.

Name	*National Biodiversity Institute of Costa Rica-Area de Conservacion Guanacaste*	*Binatang Research Center in Papua New Guinea*	*BIOTA Southern Africa and The Future Okavango*	*Caracal Research and Conservation Project*
Peer contact	occasional exchange important for bonding (Janzen 1991), 2–5 parataxonomists work together at the same field station (13 field stations in ACG), no longer elsewhere in Costa Rica owing to absence of funding	intense—all staff based at the main campus, working in open plan labs and accommodated on site, spending about 50% of time on remote field work but always as part of a team	occasional exchange (during annual workshops and conferences, via phone), important for bonding	involvement of volunteers in projects, volunteers are briefed about paraecologists' and paraecologists are briefed about skills of volunteers, exchange of ideas between paraecologists and volunteers
Technical skills	simple sampling on horseback to sampling for DNA sequencing (Janzen 2004), extensive collecting and rearing of caterpillars and parasitoids, uploading information products onto the ACG website ("species pages"), managing complex databases for their specimens, digital photography of caterpillars and parasitoids, processing images with their own laptops	computers, macrophotography, GPS, taxonomic skills, field plant and insect sampling and survey techniques, organization of field expeditions	computer, Internet, GPS, handling of digital cameras, photography of plants for scientific purposes, use of other technical equipment for environmental monitoring (e.g., weather stations), plant and animal identification	installing camera traps and monitoring installed traps, interviewing villagers based on questionnaires, using video and audio recording devices
Salary level	equals rural middle class salary	equals rural middle class salary	equals rural lower middle class salary	equals rural lower middle class salary
Web address	www.acguanacaste.ac.cr/programa-de-parataxonomos; http://www.gdfcf.org/parataxonomists-gusaneros; http://www.inbio.ac.cr/en/	http://www.entu.cas.cz/png/index.html	www.biota-africa.org; www.future-okavango.org	www.wildlifetracking.in/project updates

local and overseas students and in training courses overseas. The long-term goal is to train paraecologists either as specialists in particular ecological methods or in particular plant or animal taxa. Paraecologists support ecological research work by collecting large sets of data and specimens and by working in often remote rainforest locations for long periods. In the laboratory, paraecologists process specimens for taxonomic analysis, sort them to morphospecies, create reference collections, prepare specimens for molecular analysis (barcoding), and manage associated ecological data in databases (examples at www.entu.cas.cz/png/caterpillars/index_n.php?s=xbrc). The BRC program is described in greater detail in Basset et al. (2000, 2004), Novotny (2009, 2010), Novotny et al. (2012), Simons (2011), and Takeuchi and Golman (2001).

BIOTA Southern Africa and the Future Okavango Project

The paraecologist program in southern Africa originates from two applied research projects, namely BIOTA Southern Africa (BIOTA) (2000–2010) and The Future Okavango (TFO) (2011–2015). Within BIOTA (Jürgens et al. 2012), paraecologists were employed to support the long-term biodiversity monitoring at standardized biodiversity observation sites along a 2000-km-long transect (Araya et al. 2009; Schmiedel et al. 2010). The ongoing The Future Okavango (TFO) research project aims to provide scientific knowledge to support sustainable land-use and resource management in the Okavango Basin (Jürgens 2013). The TFO paraecologists are members of the communities that neighbor the core research sites in Angola, Botswana, and Namibia (Schmidt et al. 2013). In both projects, the paraecologists are employed through local organizations or institutions that are part of the project and are supervised by the program coordinator or a dedicated scientist. The paraecologists come from land-user communities or rural towns and are trained during special annual training courses by the program coordinator and invited guest trainers. They support the research activities of scientists in a broad range of disciplines including soil science, ecology, anthropology, and economics. They work together with the scientists but also in their absence, performing allocated tasks and helping improve communication and relationships between the scientists and the local communities. An important aspect of the paraecologists' work is to assist scientists with local logistics and guidance in the context of unfamiliar local culture and language.

Caracal Research and Conservation Project

The paraecologist program in India was initiated by the Caracal Research and Conservation Project (CRCP) in the state of Madhya Pradesh. The paraecologists are employed by CRCP and hosted by a local wildlife lodge. The lodge provides long-term support for the paraecologists and interfaces between them and visiting wildlife tourists. In the CRCP paraecologists are involved in wildlife and social surveys and in conservation actions. They help fulfill the need for systematic and continuous long-term information on rare and difficult-to-study mammalian carnivore species and the assessment of anthropogenic influences on the carnivores and their habitats. In rural India, where local culture and religion is so important in influencing human interactions with wildlife, hiring paraecologists with good knowledge of local traditional practices enables access to households, the collection of sensitive data on local people's beliefs and practices, establishment of effective communications, and maintenance of good working relationships between the project and the local community members.

Local recruits employed as full-time paraecologists are trained on the job by the program manager and principle investigator, with review and feedback sessions at the end of most working days. Three to 4 days in a month are dedicated to new skills development and refresher courses. During the absence of the principal investigator, communication with the paraecologists is maintained via telephone and Internet. The tasks of the paraecologists comprise networking with local communities, data collection and animal monitoring (wildlife surveys and interviews with local residents), documentation and storing of data according to a prescribed format, maintaining equipment, keeping records of field expenditure, and honing newly learned skills important for future work opportunities.

Program Comparison

Origin and Objectives

The programs are operated and funded by nongovernmental organizations (INBio, BRC), hybrid government–private organizations (ACG and Guanacaste Dry Forest Conservation Fund [GDFCF]), or by projects with a focus on conservation (CRCP, INBio-ACG) or applied ecological research (BIOTA and TFO). All programs aim to support the time- and labor-intensive year-around collection of field data and specimens and to foster relationships with resident neighbors. In all cases, the roles of paraecologists and parataxonomists are outcome- and process-oriented; only the focus of these aspects varied among the programs. In Costa Rica and PNG, for instance, the programs were explicitly initiated to cope with the giant task of assessing the rich under-researched biodiversity in these countries in a manageable time and at reasonable cost (e.g., Basset et al. 2004; Janzen 1991, 2004) and to provide major support for massive conservation efforts. Similarly, BIOTA's main objective for involving paraecologists was to support long-term biodiversity monitoring and to facilitate data sampling and monitoring (e.g., phenological, soil water) throughout the year where necessary (Christiaan et al. 2009; Schmiedel et al. 2010). Over time the role of the paraecologists as a local contact, who facilitates interaction between the local and scientific communities, became increasingly important. In INBio-ACG, TFO (Schmidt et al. 2013), and CRCP the paraecologists and parataxonomists as local contact people played a significant role from the beginning.

Implementation

Candidate paraecologists and parataxonomists are mainly recruited through advertising in neighboring communities and interview-based selection (INBio-ACG, BRC, CRCP, BIOTA, and TFO). In some cases, community leaders are actively involved in the selection process (BIOTA, CRCP). For BRC, the focus is on developing research capacity for biodiversity nationwide and locally in regions critical for biodiversity and conservation. The priorities are reflected in a two-pronged strategy for paraecologist recruitment at BRC that combines targeted recruitment from conservation-oriented communities with nationwide recruitment of the most qualified candidates. In terms of developing good relationships with resident communities, the former approach may seem preferable because the locally recruited candidates have detailed knowledge of the social fabric and power relationships in their own community. At the same time, however, they may be placed in uncomfortable situations when the interests of research do not align with those of the local community, such as when hiring local employees or selecting study sites. Paraecologists and parataxonomists operating in non-native communities may face fewer constraints in managing research activities, while still understanding well the social dynamics of the collaborating community.

Candidates were often identified based on previous experiences of researchers working with them (BIOTA and TFO) or explicitly tested through preliminary employment as insect collectors (BRC). The selection criteria are identical among the programs; only their relative importance varied. None of the programs require candidates to have any level of tertiary education. The BRC paraecologists, for instance, represent a wide range of education levels from 6 years of primary school education to a bachelor's degree in science. The candidates are expected to have knowledge of their environment and its organisms and general interest in the living environment and to be reliable and prepared to work in remote areas in the field, as well as to have the intellectual capacity and aptitude to learn new techniques and become computer literate. Depending on the project's needs, communication and language skills might be prioritized above local environmental knowledge (TFO). Other than INBio-ACG (Janzen & Hallwachs 1992; Janzen et al. 1993) and BIOTA (Schmiedel et al. 2010), which deliberately aimed for gender balance among the parataxonomists or paraecologists, the programs were strongly male dominated (Table 1). Working in the field seems to be a male domain in many of the respective societies; future programs should aim to achieve gender balance.

In all cases, paraecologists and parataxonomists are subject to a probation phase of 1 (CRCP), 3 (BIOTA, TFO, INBio-ACG), or 6 months (BRC). Salaries depend on the local standards and employees' experience. However, in all cases they significantly exceed the salary of day laborers and are roughly comparable to the salary of a middle-class rural worker (Basset et al. 2000; Janzen 2004). They may also include above-average employment benefits, including medical care or accommodation. Paraecologists and parataxonomists are either employed for a particular project with a definite life-span or have tenure-track staff positions in a nongovernmental organization or government. For the latter, in addition to higher job security and thus desirability for applicants, there is more scope for detailed and longer-term training, which expand the range of roles paraecologists and parataxonomists can perform. Even if the research project funding is relatively long term (more than 6 years in the case of BIOTA), the limited life-span still implies that skills for future working opportunities should be part of the capacity-development program. To ensure a longer-term perspective, some programs are designed to be an integral and daily part of the conservation area administration (ACG) or have the backing of the host organization, as is the case for GDFCF funding of INBio-ACG parataxonomists (GDFCF 2015). The CRCP (a registered foundation created by Panna Tiger Reserve in India) is exploring an option to provide a platform through which paraecologists can be recruited by future projects working in the Panna region. Similarly, the INBio-ACG is affiliating itself with a registered government–private partnership organization to create a host organization for paraecologists or parataxonomists. Other strategies for longer-term careers could be provided by a single institution (assuming ability to attract successive research or conservation projects) or by an emerging job market of critical size where institutions or research or conservation projects offer enough job opportunities for trained paraecologists and parataxonomists. These could include positions in tourism, conservation, academia, or the government.

Besides long-term employment, another aspect in which the programs differ from citizen science is the continuous capacity development afforded by direct interaction with scientists. While working with academic scientists or experienced practitioners, paraecologists and parataxonomists learn about scientific concepts, methods and taxonomy and about professionalism at work (Janzen et al. 1993; Schmiedel et al. 2010), as is the norm for graduate students. The on-the-job training continues for entire careers of several decades with varying intensity, depending on the availability of the scientists and the work process. For BRC and INBio-ACG, training is particularly intense during the first 6 months on the job and constitutes a probation period during which new staff has to demonstrate their interest and suitability for the job. In the following 2.5 years, paraecologists and parataxonomists occupy junior positions, over which time their salaries gradually approach senior level, based on the training completed.

In addition to the continuous on-the-job learning, all employees take special training courses of varying lengths and intervals (Table 1) or, as is the case for BRC, take courses organized jointly for paraecologists and local and overseas students. The set up and schedule of the training courses depends on the requirements of the programs. The courses are conducted either largely by scientists, who also coordinate the program supported by a few guest trainers (BIOTA/TFO, CRCP), or by collaborating scientists, who directly benefit from the paraecologists and parataxonomists trained in a certain field (INBio-GCA, BRC). Often experienced paraecologists and parataxonomists are mentors of their peers (INBio-ACG, BRC). Capacity development among programs also differed, depending on the project objectives and local needs. For the biodiverse countries Costa Rica and PNG, the need is to promote a rapid attainment of self-reinforcing taxonomic literacy and improved awareness of biodiversity's importance (e.g., Janzen 1991; Basset et al. 2004; Novotny et al. 2012). The training courses within BIOTA and TFO cover the research activities paraecologists are involved in through the project, for example soil sampling, biodiversity assessment and monitoring, household interviews and harvest yield assessment, as well as a broad range of other technical skills.

The programs are locally adapted and deal with the social fabric and constraints of the societies they work in. In South Africa and Namibia, for instance, the legacy of colonialism and apartheid still has negative effects on the formerly disadvantaged rural communities. The situation in Costa Rica is similar, and many ethnic groups still struggle to maintain their cultural heritage. In India a rigid caste system, traditional social hierarchy, and large economic parity between urban and rural groups limits developmental possibilities for those lower in the social and economic strata. As a result, levels of formal education in rural areas are low and people become underprivileged with poor prospects to access education and training that would help them improve their economic and social standing. The paraecologist and parataxonomist programs aim to break this traditional mold and integrate the knowledge of people in low social and economic classes into science and conservation. Training therefore comprises soft skills such as intercultural communication, project planning, budget management, and dealing with conflicts and skills that help participants cope with challenging situations in their professional and personal lives. The programs also aim to increase awareness of the value of local traditional cultures and practices.

Paraecologists and parataxonomists in the programs we examined have a broad portfolio of tasks: collection, processing of specimens, rearing of animals, data entry, taking photographs, writing species pages, teaching, mentoring, guiding visitors, conducting expeditions, maintaining vehicles or scientific equipment (INBio-ACG, BRC, BIOTA, and TFO), biodiversity monitoring (BIOTA, CRCP), supporting all types of research of social and natural scientists in the field of ecosystem service assessment (BIOTA, TFO, INBio-ACG), and facilitating communication between scientists and communities (INBio-ACG, BIOTA, TFO, and CRCP). In INBio and BRC, where the paraecologists and parataxonomists have broad training in rainforest ecological research and detailed training in very specific tasks, they typically specialize in certain taxonomic groups. For instance, the best local experts on PNG birds and butterflies are BRC paraecologists, and INBio-ACG parataxonomists have inventoried more than 13,000 species of caterpillars and parasitoids. This level of expertise can be reached because of long-term employment (e.g., 9 years on average at BRC; 15 years in ACG). It justifies co-authorship of research papers (e.g., Novotny et al. 2007; Sam et al. 2014) and website content (e.g., http://www.acguanacaste.ac.cr/paginas-de-especies). This way, paraecologists and parataxonomists contribute to society and to science through high-quality collections and observations.

A very important aspect of the paraecologist and parataxonomist programs is the mentoring and supervision of their work. For example, in the INBio-ACG, BRC, and CRCP programs, where they are employed by a local organization with a central facility, paraecologist and parataxonomist have an institutional home and mentors, even if their place of work is a forest and they communicate primarily by email. Working in isolated situations without regular face-to-face supervision, it is a challenge for paraecologists and parataxonomists to maintain momentum, and they can sometimes fail to meet expectations. Some programs (CRCP, BIOTA, and TFO) successfully rely on remote supervision for several months of the year, maintaining contact by web and email (INBio-ACG, TFO, CRCP) or phone (BIOTA, CRCP). Continuous on-site supervision, however, is most advisable.

Paraecologists or Parataxonomists and Their Communities

Parataxonomists and paraecologists of all four programs live in rural areas with very few opportunities for permanent employment. A regular, reliable income and the social security that comes with it are therefore very important. Perhaps even more important than monetary income per se is capacity development and social promotion from day labor to middle-class worker with associated responsibilities and job security (BIOTA, TFO, CRCP, INBIO-ACG) (Basset et al. 2000; Janzen 2004; Christiaan et al. 2009). This security can have positive knock-on effects such as investment in the education of their children (INBio-ACG, BIOTA, TFO).

Besides the income, they have the opportunity of personal development. They develop pride in collecting quality material for museums (INBio-ACG, BRC, BIOTA) and in contributing to science and environmental conservation (INBio-sACG, BIOTA-TFO, CRCP). Gained skills, access to an international network of social contacts represented by their research collaborators, ability to operate equipment (laptop, cameras, GPS devices), their contribution to often seemingly obscure scientific goals, and being paid for their traditional skills (INBio-ACG, CRCP) make them proud of their jobs and influential in their communities. Being part of a professional team, they learn to express their views openly and professionally with researchers, which is unusual in the complex social hierarchal structure prevalent in India and many other tropical countries. This personal development and promotion can also lead to envy and ensuing social problems, particularly in egalitarian societies, where their position as facilitators of potentially prestigious and lucrative research projects may interfere with more traditional power structures. Their involvement in research can also become a stepping stone to other professions, such as positions in tourism, conservation, academia, or the government. For instance, 6 paraecologists from BRC continued their studies at a university and completed academic degrees in biology. One BIOTA paraecologist and many INBio-ACG parataxonomists have gone on to hold government positions in conservation administration (Basurto 2013*a*, 2013*b*; Basurto & Jiménez-Pérez 2013).

Another benefit of the programs is that the paraecologists and parataxonomists provide role models for younger generations. They are proof that there is a chance for social advancement in their own communities (INBio-ACG) (Janzen 2004) (BIOTA, TFO, CRCP). They are also influential in raising awareness of the value of the environment among community members and in strengthening the relationship between researchers and local stakeholders. Visits to local schools and inviting interested children to join them in the field (BRC, BIOTA) helps encourage perception of the natural environment as a productive place in its own right (Janzen 2004). The BRC, for instance, recruits some paraecologists from communities in the vicinity of conservation areas, which over the years has strengthened the support for these areas. Finally, with their new skills and technical equipment, paraecologists and parataxonomists become important resource persons in their communities because they can use computers to type letters and to search for information on the Internet and can use digital cameras to take photographs to document public or private events.

Achievements for Science

All the programs have been instrumental in supporting and speeding up research in remote areas. For programs that focus on collecting, recording, and processing plant and animal specimens and making other observations for biodiversity assessment (INBio-ACG, BRC, BIOTA), the quantity of the collected material and the publications that ultimately emerge from the work are 2 important criteria. In this respect, the parataxonomists in Costa Rica are a powerful natural resource management technology (Janzen & Hallwachs 2011). In all programs, paraecologists and parataxonomists help researchers access geographical areas, research topics, or gain access to marginal social groups that are otherwise difficult to reach due to topographical, language, social, and cultural barriers and timing.

Other benefits of the programs are less straightforward to quantify. Scientists from all four programs appreciate the positive contribution of the paraecologists and parataxonomists to the integration of local knowledge into science, communication of scientific outcomes to the communities, intercultural learning, diffusion of tension between communities and scientists, and the perception of the research by the community (Janzen 1991, 2004; Schmiedel et al. 2010). Paraecologists and parataxonomists are also instrumental in managing local logistics, keeping an eye on and maintaining research equipment, organizing meetings, and keeping contact with stakeholders (BIOTA, TFO, CRCP, INBio-ACG).

Paraecologists and parataxonomists make excellent collaborators for postgraduate students because they often have detailed knowledge of the studied taxa or ecosystems, while the students are better equipped theoretically. Joint field campaigns, which mean sharing meals and sleeping and washing facilities, let them get to know each other better and in many cases lead to long-lasting friendships.

Challenges

The challenges the programs face are related to their specific characters or emerge from external circumstances. Typical project-related challenges emerge from the remoteness of field sites. Parataxonomists and paraecologists may perceive it as problematic for their personal life if they are absent from family and friends during extensive expeditions (50% of their work time [BRC]) to remote locations or during field work of several weeks in a row (BIOTA, TFO). Remoteness of the study areas may also limit contact with supervisors or mentors. Particularly at the beginning of their career, paraecologists and parataxonomists need regular supervision and feedback to improve their work (e.g., quality and quantity of specimens and data). Lack of supervision slows down the learning curve of scientists and paraecologists and parataxonomists and limits the range of tasks that can be done. Ideally, mentors should work from the same place, have their own interest in this cooperation, and a have long-term commitment to building a trusting relationship. If scientists are based far away, Internet and telephone contact encourages the self-dependence of the paraecologists or parataxonomists enormously (INBio-ACG, TFO, CRCP). If technical deficiencies interfere with this contact, however, it can cause interruption of communication with their mentors for weeks, leading to frustration and even misunderstanding on both sides (BIOTA, TFO).

Lack of funding is a threat for even long-term programs (INBio-ACG, BRC, CRCP) (Simons 2011; Wade 2014), so sometimes paraecologists and parataxonomists have to look for new work opportunities. Trained and experienced paraecologists and parataxonomists are more likely to get local jobs that do not require an academic degree than other school dropouts. For many training-specific jobs (e.g., field assistant, conservation warden), however, they have to compete with applicants with undergraduate degrees.

Parataxonomist and paraecologist programs are sometimes subject to fundamental misconceptions. One example is the criticism that naïve species concepts lead to misleading biodiversity analyses by naïve taxonomists (e.g., Krell 2004; Baraloto et al. 2007; Abadie et al. 2008). Here we explored the potential for paraecologists and parataxonomists to facilitate research in collaboration with scientists so that the biodiversity studies are faster, cost-efficient, and of better quality than they would be otherwise. The assumption that parataxonomists and

Table 2. Comparison of paraecologist and parataxonomist programs with citizen science programs.

	Paraecologists and parataxonomist programs (references cited in text)	*Citizen science (e.g., Silvertown 2009)*
Aim	support time- and labor-intensive data gathering	support time- and labor-intensive data gathering
Target group of the program	individuals (paraecologists and parataxonomists) and their communities	public (citizen scientists)
Involvement	full time as part of the vocation (professional)	transient voluntary basis (lay person)
Research topics	any topic, provided the paraecologists and parataxonomists are adequately trained and equipped	mainly dominated by topics that ignite the interest of the public
Tasks	involved in data capturing and processing	involved mainly in data capturing but recently more focus on processing too
Methods	scientific methods through training and close cooperation with scientists	mainly focused on observation-based recording (geographical location an important aspect), photographic documentation
Recruitment	selection process and probation phase	mostly open access
Investment and commitment	investment in people, their research equipment, and infrastructure	investment in communication infrastructure (platforms, etc.) and awareness raising
Relationship to scientists	member of the research team, direct personal interaction, continuous exchange with scientists	indirectly linked to research team, exchange via internet platforms, etc. or in the past commonly via post
Impact of training	intensive, continuous training, holistic capacity development, and social promotion of paraecologists and parataxonomists	minimal direct specialist training (if any) or technical introduction into specific methods, more focused on creating interest and raising awareness of citizens
Quality of data	direct contribution to complex data such as host specificity of insects or parasitoids	often documentation of observations such as birds and invasive species, only recent focus on recording of interactions

paraecologists are employed to produce morphospecies or parataxonomist units (sensu Krell 2004) is unfounded and based on erroneous association of the terms *parataxonomy* and *parataxonomic units* with *parataxonomist*. Undoubtedly, traditional morphological taxonomy is in a critical condition (Godfray 2002), but the solution lies in more extensive use of molecular information and tools (e.g., Ratnasingham & Hebert 2013; Riedel et al. 2013), which can be supported by paraecologists and parataxonomists (Janzen & Hallwachs 2011), not in simplified morphological approaches.

Paraecologists and Parataxonomists and Citizen Science

The principal difference between the use of paraecologists and parataxonomists and citizen scientists is the intensity of participant involvement (Table 2). In citizen science, participants are volunteers and their collaboration is nonbinding and often underpinned by a diverse range of motives. Parataxonomists and paraecologists, however, are long-term employees selected through a competitive process who undergo intensive, continuous training during their entire career. They can therefore be considered professionals in their field. Their professionalism and close cooperation with scientists allows for the application of complex methods of data sampling and an advanced level of data or collection processing. This is why paraecologist and parataxonomist programs can be viewed as advanced relative to citizen science programs. Paraecologists and parataxonomists work on research topics that are not necessarily popular among the broader public, whereas it can be difficult to recruit citizen scientist to volunteer in some areas (Silvertown et al. 2013). The long-term commitment of paraecologists and parataxonomists can be instrumental in bridging the gap between science and local knowledge and building trusting and productive relationship between themselves, the scientists, and neighboring communities. From this perspective, the programs can support participatory action research (Reason & Bradbury 2001) or transdisciplinarity (sensu Max-Neef 2005).

In contrast to citizen science, the professional nature of a full-time paraecologist or parataxonomist and expectations for their continuous development requires ongoing funding for salaries, equipment, and training. Whilst benefiting in terms of scientific output and mutual learning, the programs thus need a long-term perspective in terms of financial and personal commitment to build interpersonal trust, as well as funding and organizational security. Both paraecologist and parataxonomist and citizen science approaches have their merits, depending on the scientific objectives and social-environmental context.

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